RESEARCH & DEVELOPMENT

Affordable Pre-Finishing of SiC for Optical Applications

Mirror Technology Days 2009

Albuquerque, NM

Presented by:

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Creare Inc.

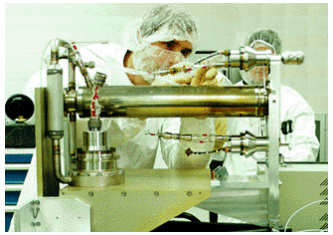
Presentation Outline

- Introduction to Creare
- Background
- Innovation
- Phase I Results
- Program Overview
- Summary

RESEARCH & DEVELOPMENT

Creare Incorporated

- "Problem Solvers"
- Contract Engineering R&D
  - Diverse Technical Expertise
  - Extensive Facilities
- Industrial & Federal Client Base
- Founded 1961
- Partnership of Engineers
- Technology Commercialization
  - Licensing
  - Spin-off Companies
  - Custom Products
  - Phase III
- Spinoffs
  - 9 Companies/1900 Employees
  - Revenues $400 M/year



Crycooler for HST

Catapult Gap-Width Measurement Device

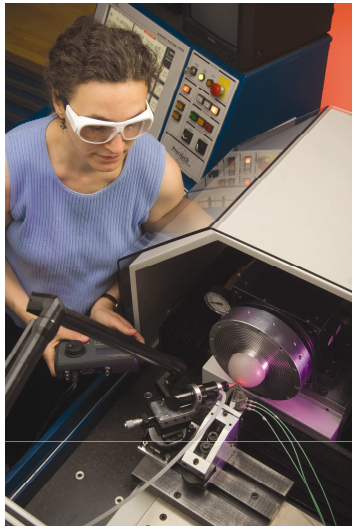
Anti-Corrosion Coverings

RESEARCH & DEVELOPMENT

Technology Areas

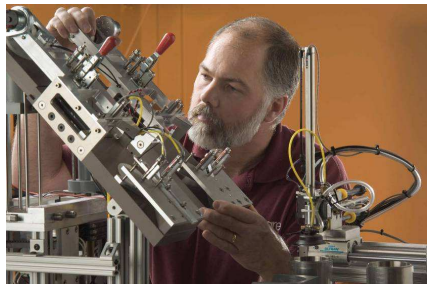
- Fluid Dynamics & Heat Transfer
- Biomedical
- Cryogenics
- Software & Data Systems
- Manufacturing Technology
- Sensors & Controls

Miniature High-Speed Turbine



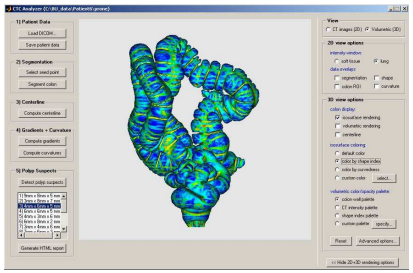
Laser-Assisted and Ultra-Precision Machining

Advanced Head/Hearing Protection for Carrier Deck Crews

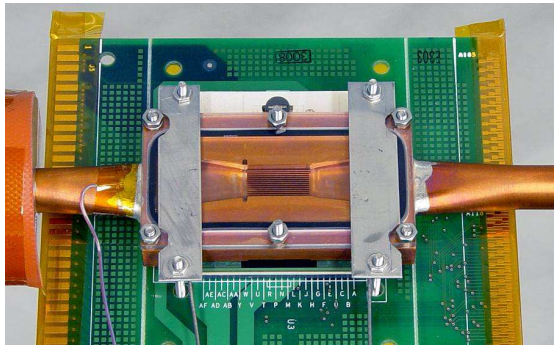


Automated Assembly for Thermal Batteries

Image Reconstruction for Virtual Colonoscopy



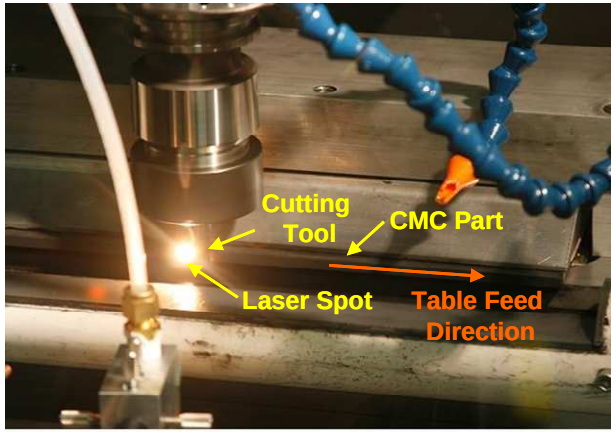
Turnkey High-Performance Data Acquisition and Processing System



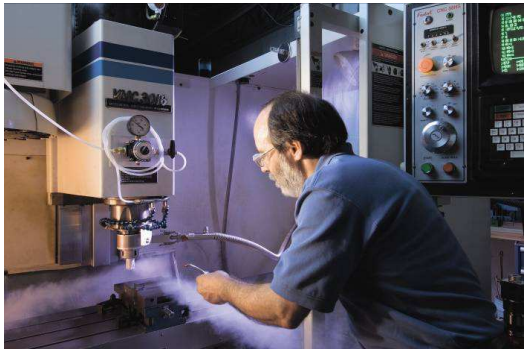
Microchannel Evaporator for Microprocessor Cooling

RESEARCH & DEVELOPMENT

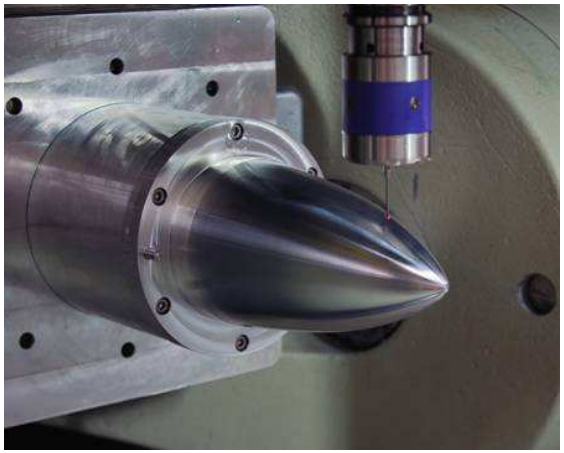
Advanced Manufacturing at Creare



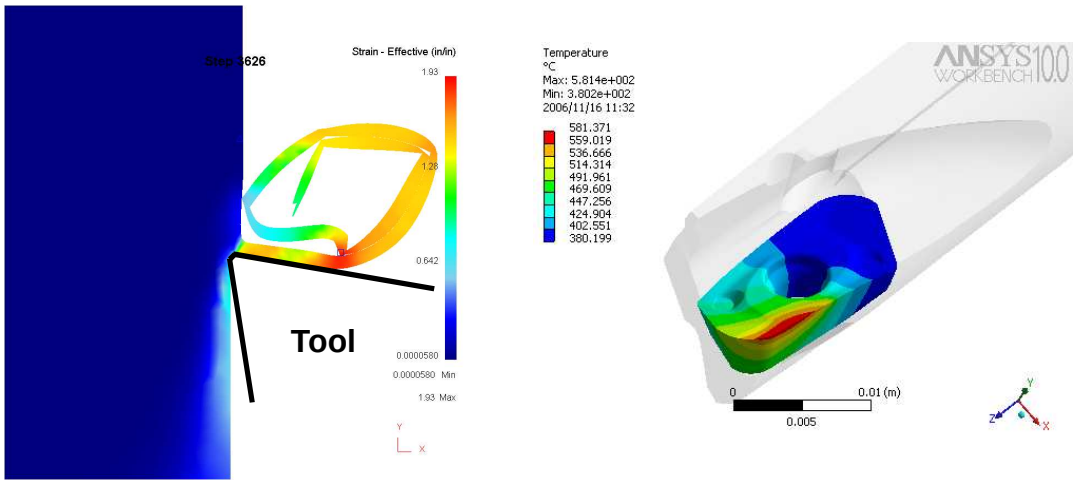
Laser-Assisted Machining



Indirect Cooling for High Performance Machining



On-Machine Inspection and Tool Path Correction

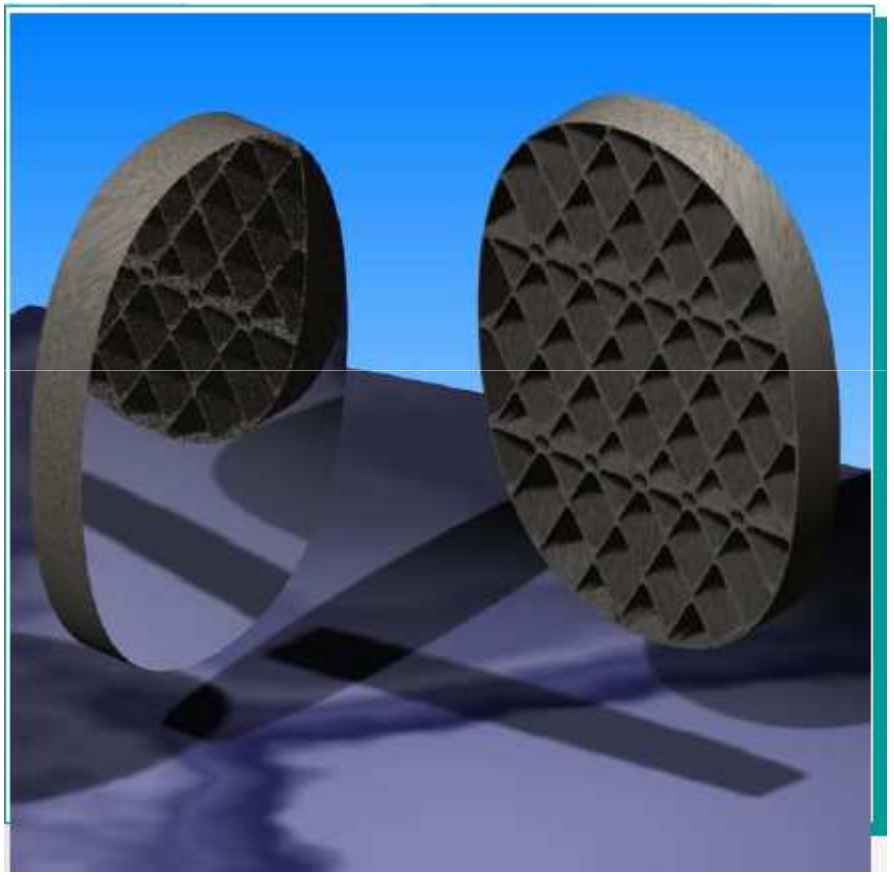


Modeling and Simulation

Hybrid Processing for Ceramic Mirrors

Silicon Carbide Optics

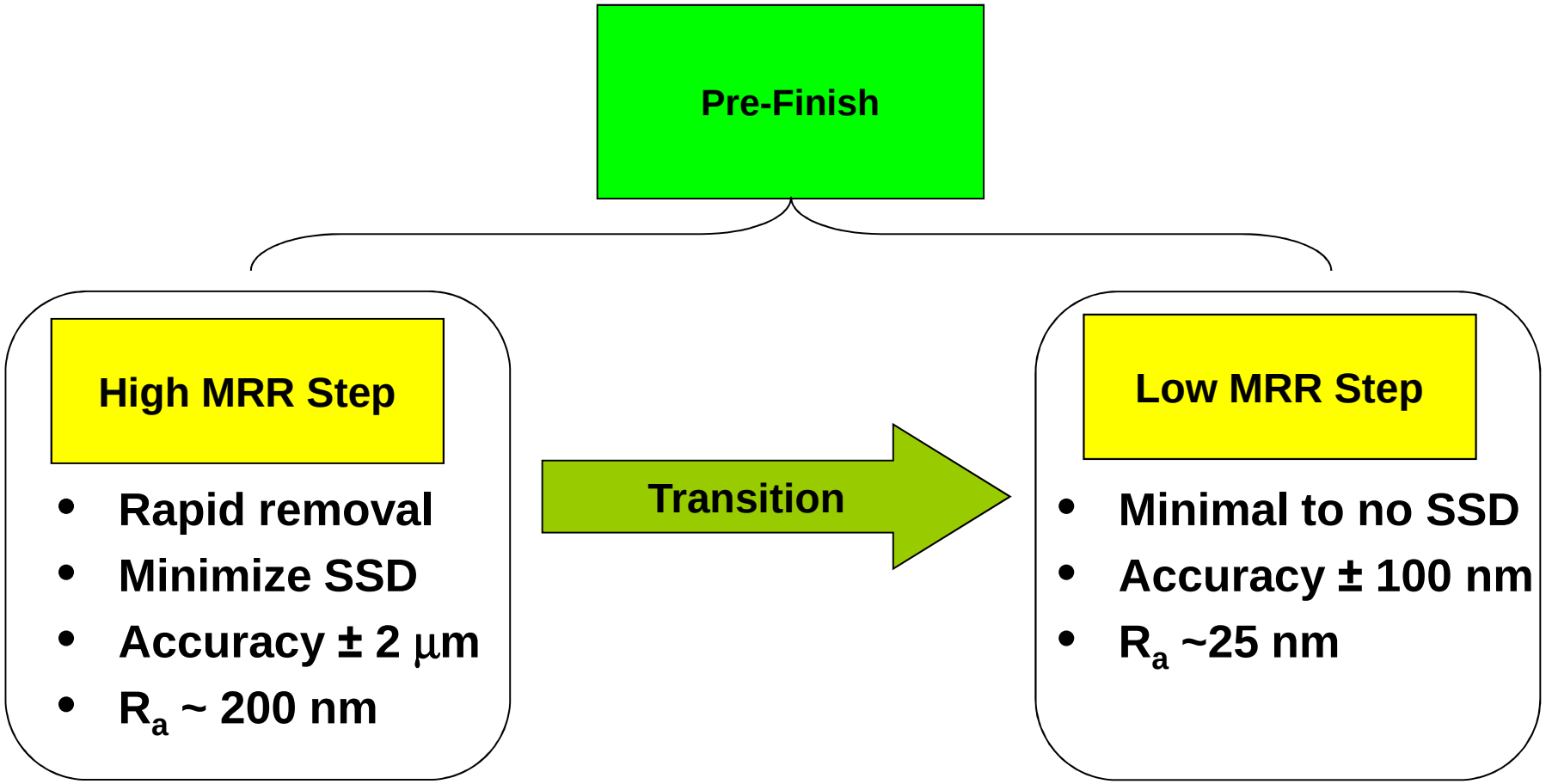
- **Silicon carbide is an excellent candidate to replace beryllium in lightweight optics**
- **Eliminates toxicity concerns**
- **Lightweight, thermally stable**
- **Cost-effective manufacturing remains a challenge**



Overall Manufacturing Process

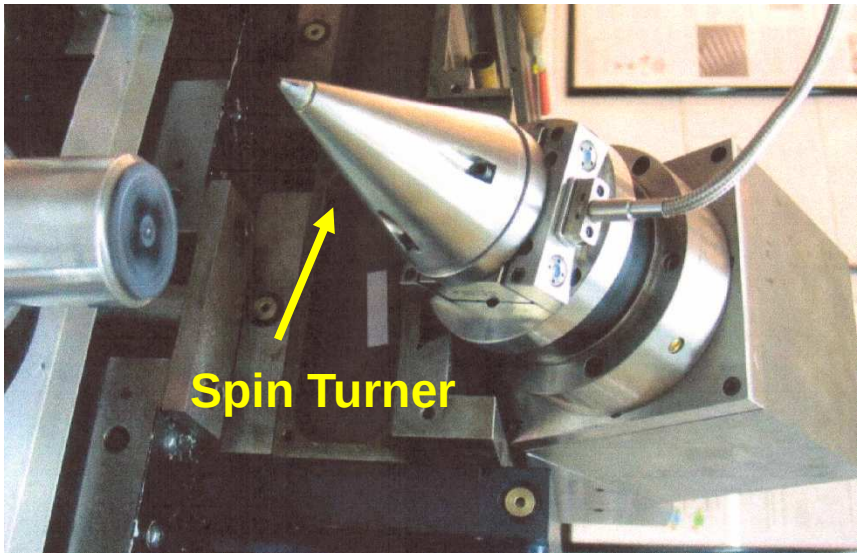
R_a	Moderate (~2 μm)	Low (~25 nm)	Very Low (~5 nm)
Accuracy	± 25 μm	± 100 nm	± 10 nm
MRR	N/A	High/Low	Low
Process	Single Step	Multiple Steps	Single Step
Cost	$$	$$$$	$$

Pre-Finishing Process

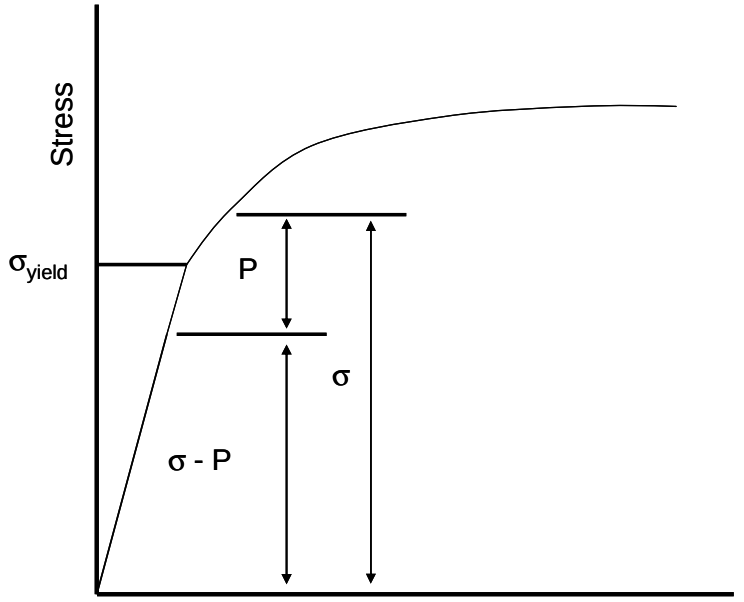


Our Hybrid Machining Approach

- Use single-point diamond turning (SPDT)
- High MRR Process: Spin-turning
- Low MRR Process: Ductile-regime machining (DRM)



Spin Turner for High MRR Step

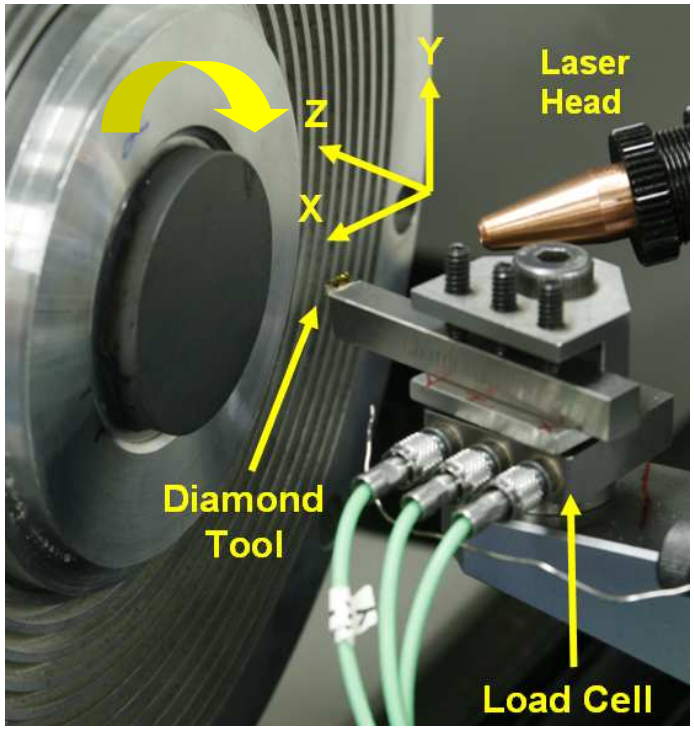


Stress-Strain Curve Demonstrating Low-MRR DRM Process

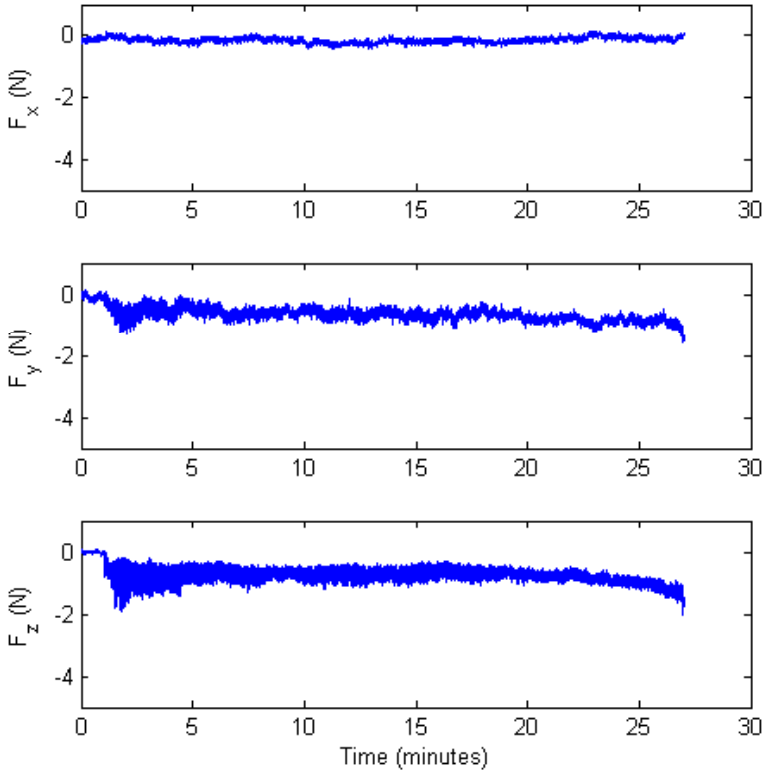
Phase I Objectives Achieved

- **Demonstrated Feasibility of Machining CVD SiC**
  - **Successfully machined material to near-optical quality**
  - **Demonstrated use of DRM for low MRR step**
- **Demonstrated Cost Savings**
  - **Completed detailed cost analysis**
  - **Showed that other options are as much 85% higher cost**
- **Developed a Plan to Scale-Up**
  - **Developed the hybrid approach**
  - **Both based on SPDT**
  - **Sufficient to machine optics for NASA**

Phase I Technical Achievements



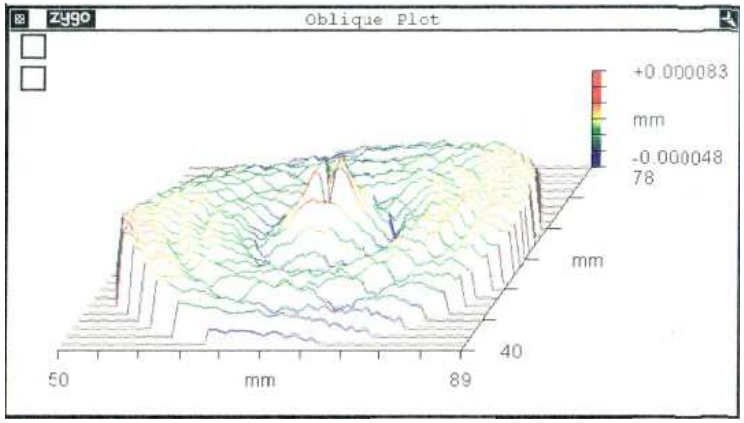
Setup for Low MRR Tests



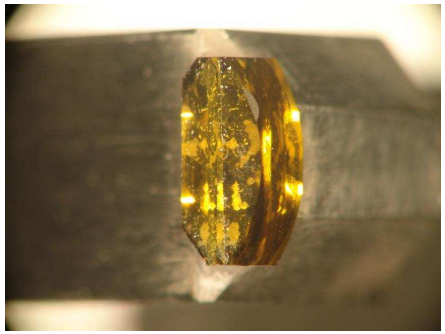
Measured Cutting Forces

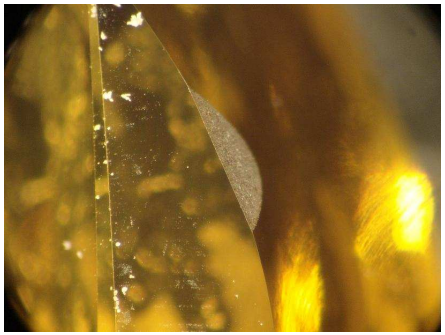
Phase I Technical Achievements

Mirror-Like Surface Produced in CVD SiC

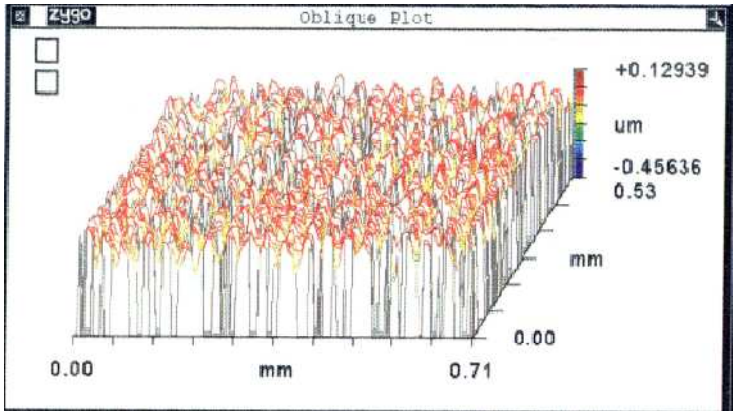


Wavefront Profile (~40 nm variation)





Tool Wear After ~100 Cuts

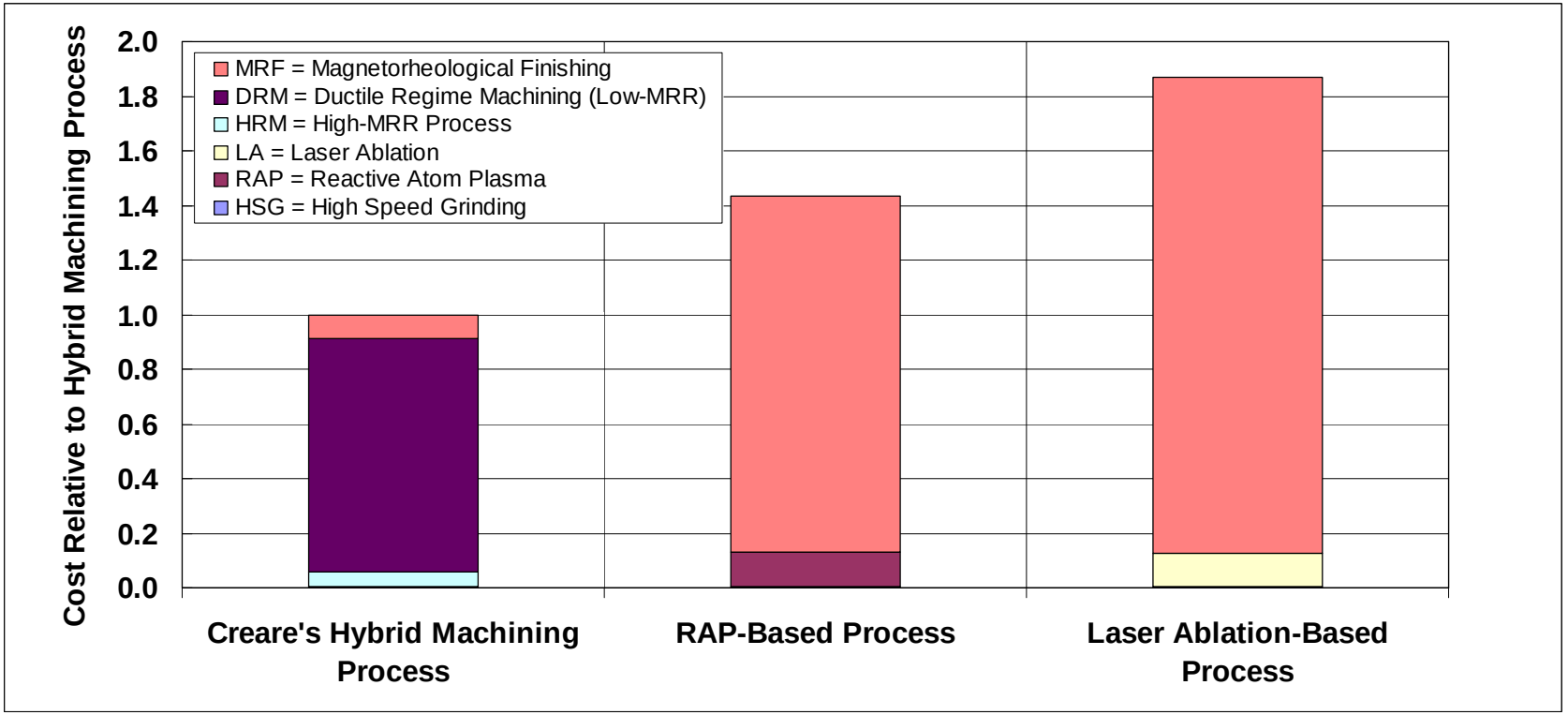


Roughness (~45 nm R_a)

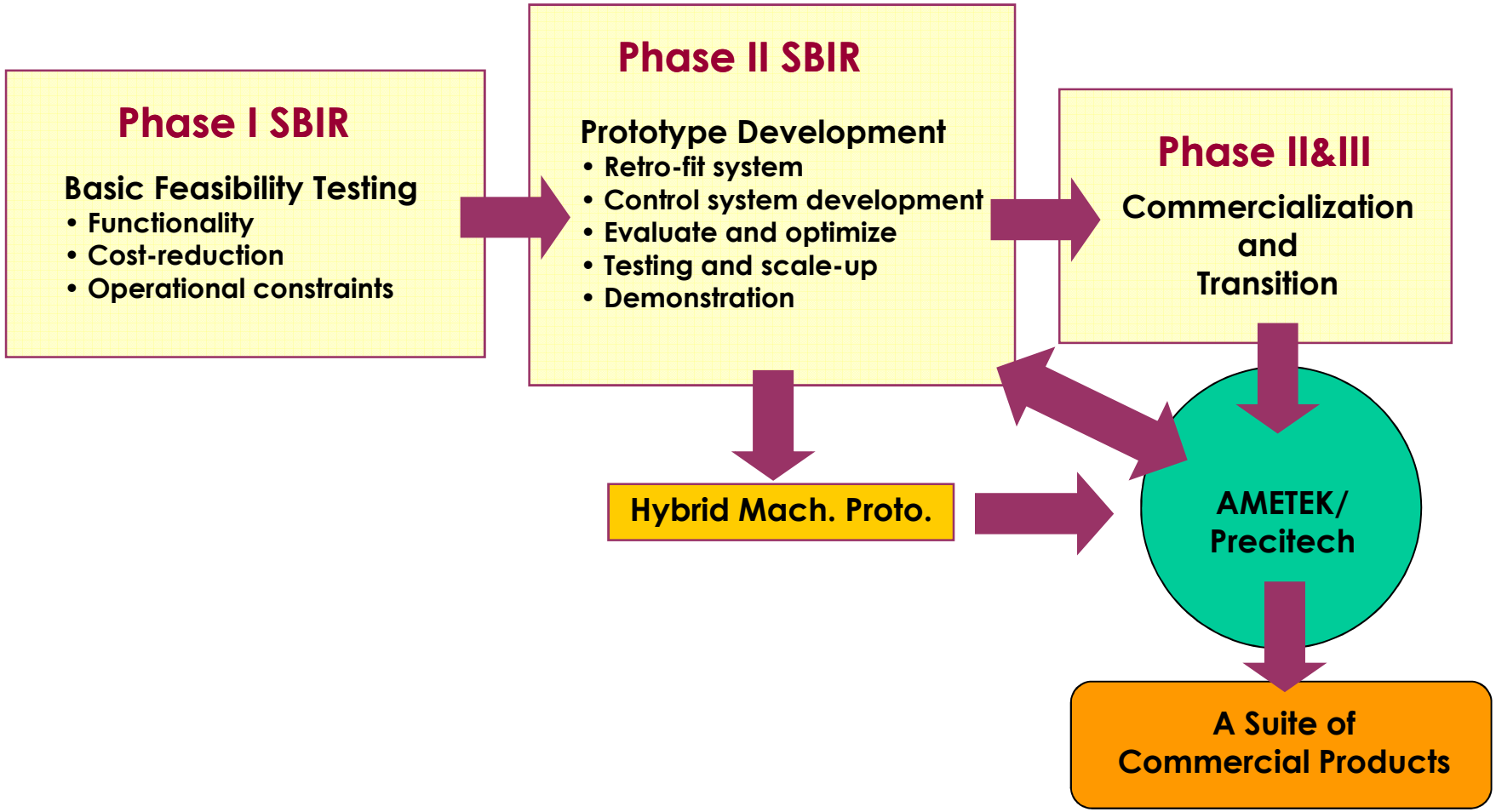
Cost Evaluation

- **Key Assumptions**
  - **Conical shape ~254 mm in diameter**
  - **100 μm of material needs to be removed**
  - **Same cost (man and machine) for each process**
  - **Assumed that we need to remove 2.5 times the final R_a during finishing**
  - **Cutting tools accounted for in estimates**
- **Cases Evaluated**
  - **Creare Process (High MRR: 2 mm^3/min, R_a~1000 nm, Low MRR: 0.025 mm^3/min, R_a~40 nm)**
  - **RAP-Based Process (1 mm^3/min, R_a~200 nm)**
  - **Laser Ablation-Based Process (1 mm^3/min, R_a~750 nm)**

Cost Evaluation



Program Overview

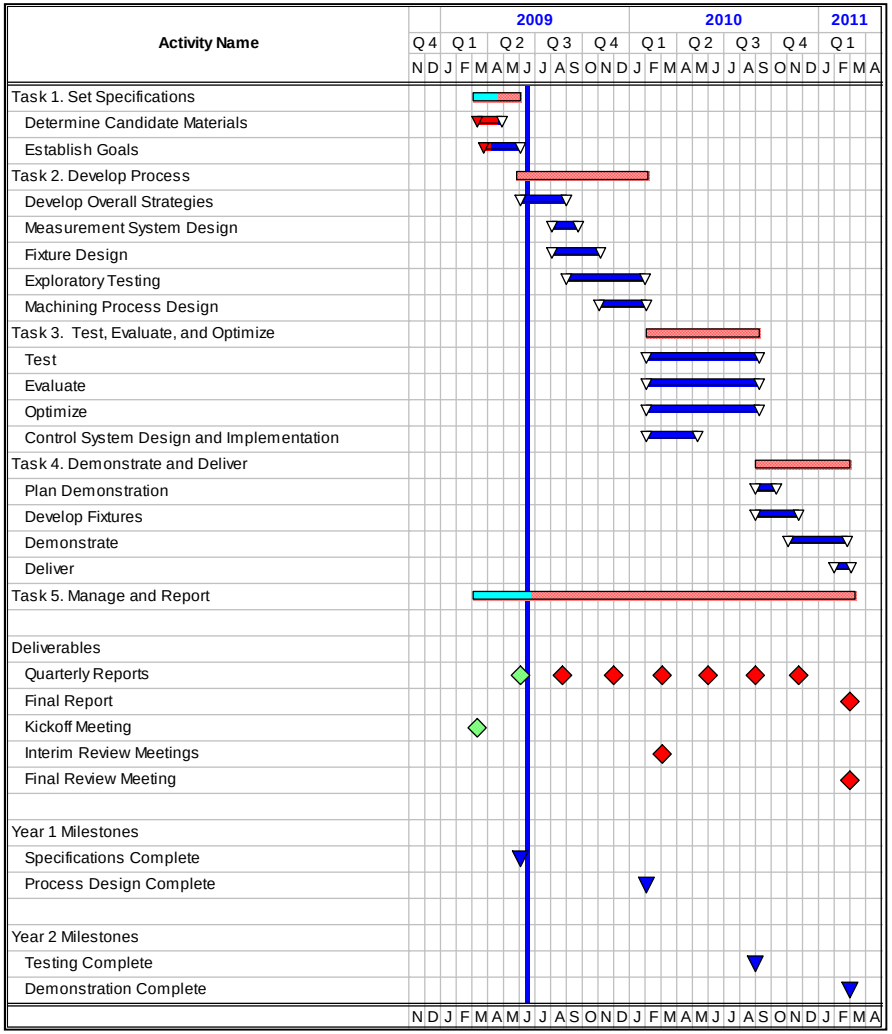


Phase II Technical Objectives

- **Optimize the Hybrid Machining Process**
  - **Further develop high MRR process**
  - **Refine low MRR process**
- **Evaluate the Performance**
  - **Coupled effects**
  - **Surface quality, part strength**
  - **Cost savings**
  - **Scale up to larger geometries**
- **Demonstrate our Approach**
  - **Machine a conical mirror (~254 mm diameter) from Trex CVD SiC**

Phase II Technical Objectives and Plan

- **Optimize the Hybrid Machining Process**
  - **Further develop high MRR process**
  - **Refine low MRR process**
- **Evaluate the Performance**
  - **Coupled effects**
  - **Surface quality, part strength**
  - **Cost savings**
  - **Scale-up to larger geometries**
- **Demonstrate our Approach**
  - **Machine a conical mirror (~254 mm diameter) from Trex CVD SiC and deliver to NASA**

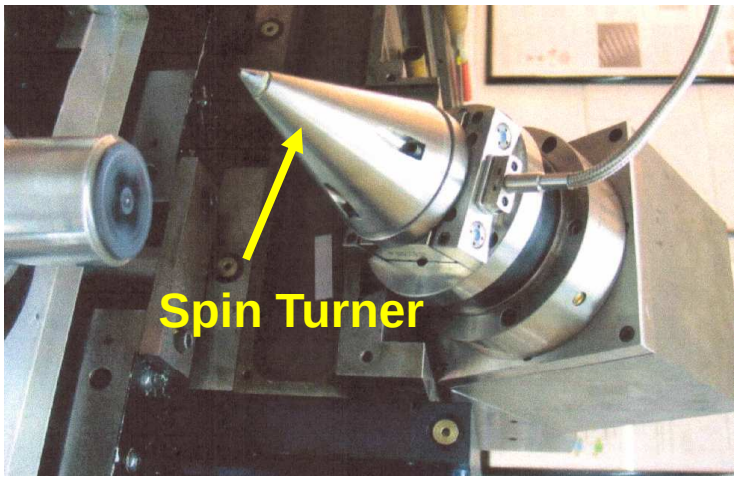


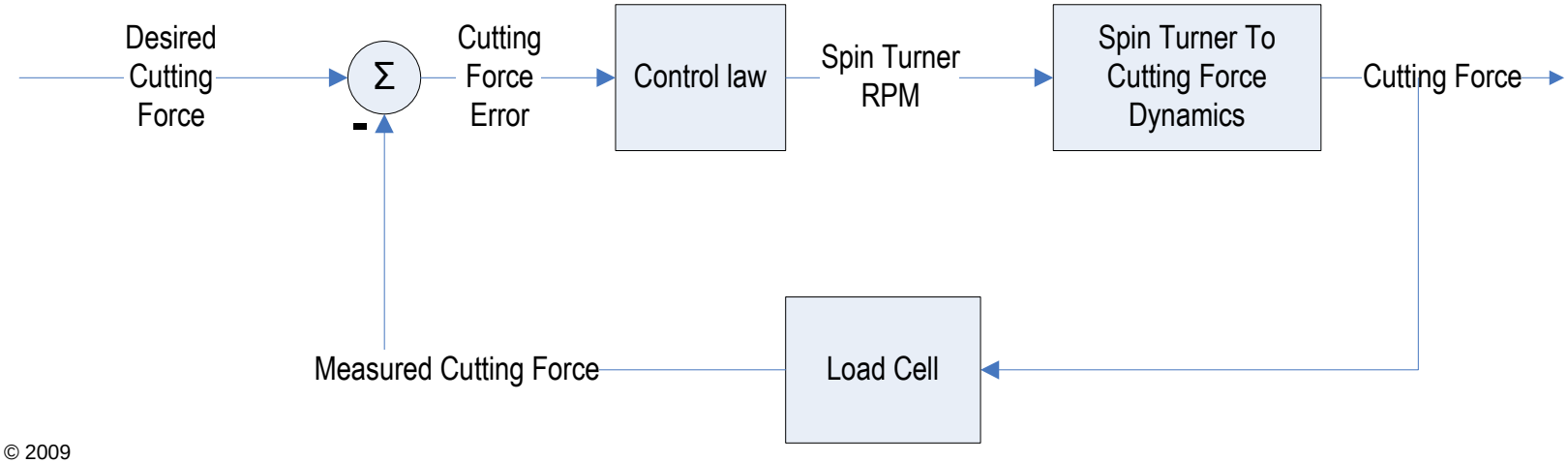
Phase II Tasks

- **Task 1. Set Specifications**
  - **Finalize material selections**
  - **Develop overall goals**
- **Task 2. Develop Process**
  - **Overall strategy**
  - **Measurement system design**
  - **Fixture design, tool mount design, process evaluations**
- **Task 3. Test, Evaluate, and Optimize**
  - **Test: Shakedown, High MRR, Low MRR, Hybrid**
  - **Evaluate: SEM Examinations, Accuracy, Roughness, Strength**
  - **Optimize**
- **Task 4. Demonstrate and Deliver**
  - **Plan**
  - **Develop fixtures**
  - **Demonstrate**
  - **Deliver**

High MRR Approach for Phase II

- **Spin Turner from Edge Tech.**
- **Rotates to maintain sharp edge at high MRR**
- **Preliminary approach for high MRR process**





Summary

- **Demonstrated feasibility and cost-effectiveness of our Hybrid Machining Approach**
- **Showed that DRM is viable process for the low-MRR phase**
- **Identified an available approach for the high-MRR process for Phase II**
- **Developed an overall program approach that focuses on commercialization and transition**

RESEARCH & DEVELOPMENT

Creare

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